(12) UK Patent Application (19) GB (11) 2 089 109 A

(21) Application No **8131827**
(22) Date of filing **22 Oct 1981**
(30) Priority data
(31) **212761**
(32) **3 Dec 1980**
(33) **United States of America (US)**
(43) Application published **16 Jun 1982**
(51) **INT CL³ H01J 35/08**
(52) Domestic classification **H1D** 11X 11Y 2A 2R 32 9C1X 9C1Y 9CY 9FX 9FY 9G 9H 9Y
(56) Documents cited
GB 1247112
GB 1219042
GB 827348
GB 602306
GB 365297
GB 237580
US 4132917A
US 3836804A
US 3158513A
(58) Field of search **H1D**

(71) Applicants
The Machlett Laboratories Incorporated,
1063 Hope Street,
Stamford,
Connecticut,
United States of America.
(72) Inventors
Thomas J. Koller,
Jay W. Shepherd,
Paul Greninger.
(74) Agents
Reddie & Grose,
16 Theobalds Road,
London WC1X 8PL.

(54) **X-ray targets and tubes**

(57) The anode 30 of an X-ray tube comprises an X-ray emissive target insert 88 of tungsten for example embedded in the surface of an anode block 52 of copper for example, the interface 122 between the insert 88 and the block 52 being concave towards the external emission surface of the insert 88. In order to prevent thermally induced stresses causing the insert to separate from the block, the interface 122 is contoured to lie on an isothermal surface and the insert 88 may thus be substantially semi-ellipsoisal. Shear stresses at the interface are thus eliminated. Cooling channels 70, 74 in the anode block can be distributed to tend to establish an isothermal surface at the interface 122.

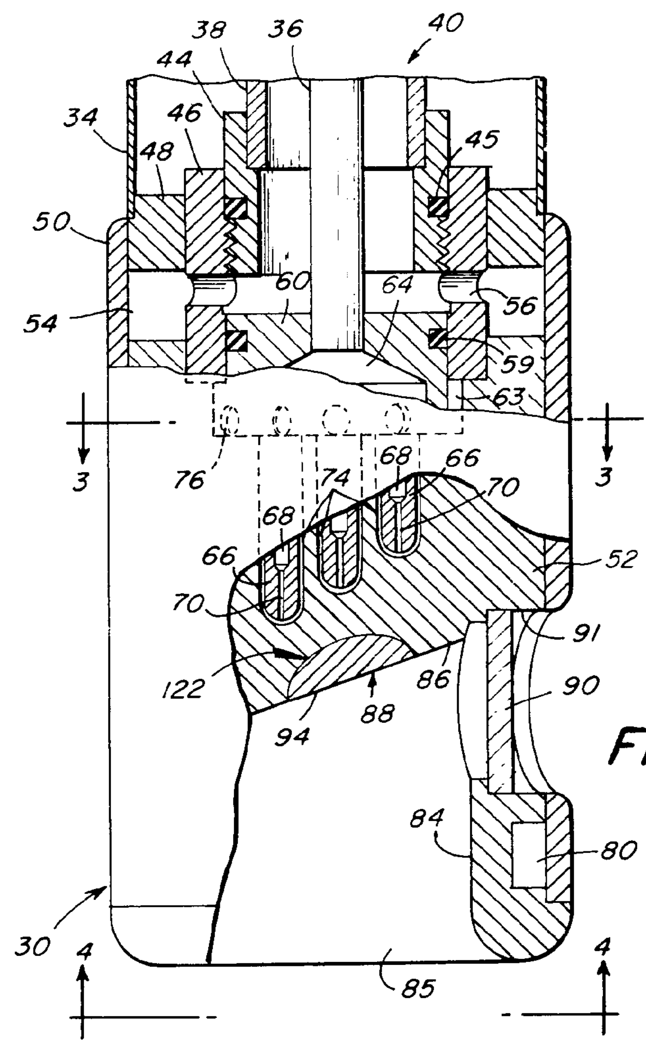

FIG. 2

GB 2 089 109 A

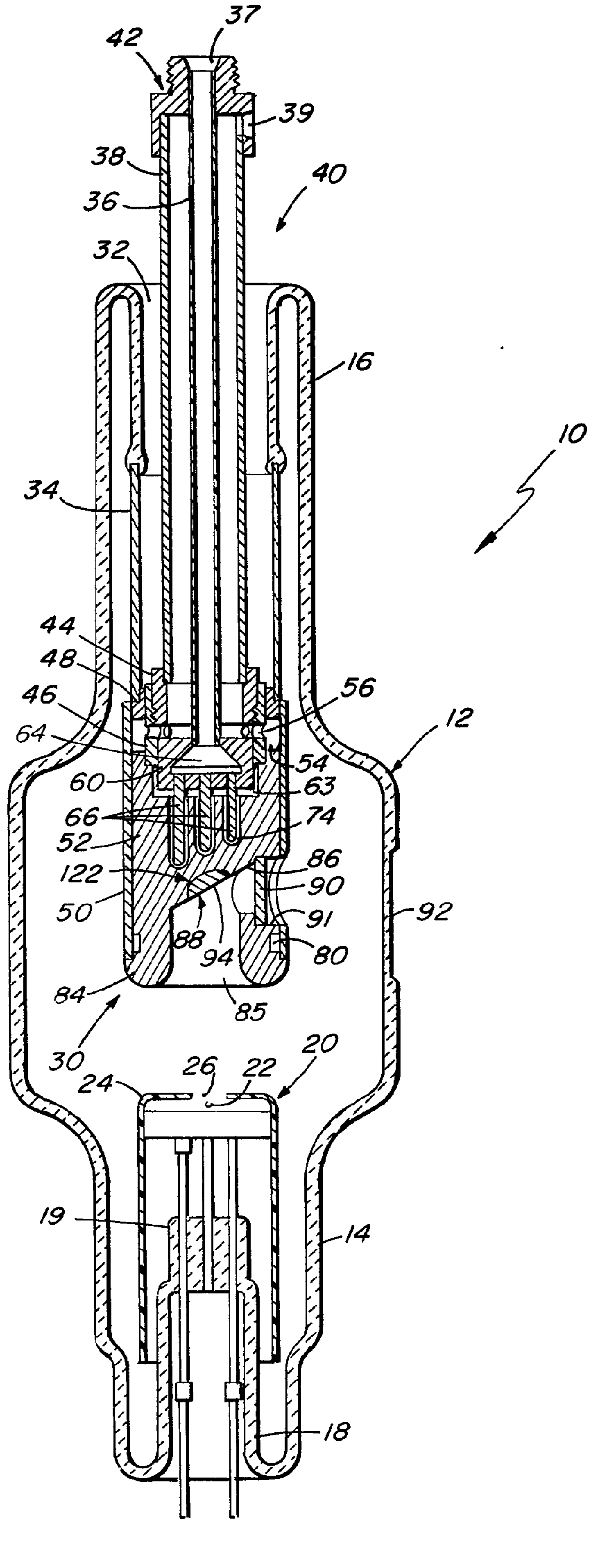
37
42
39
38
40
36
32
16
10
34
44
48
56
46
64
54
60
63
66
74
52
86
122
90
50
91
92
88
94
80
84
85
30
20
26
22
24
19
14
18

FIG. 1

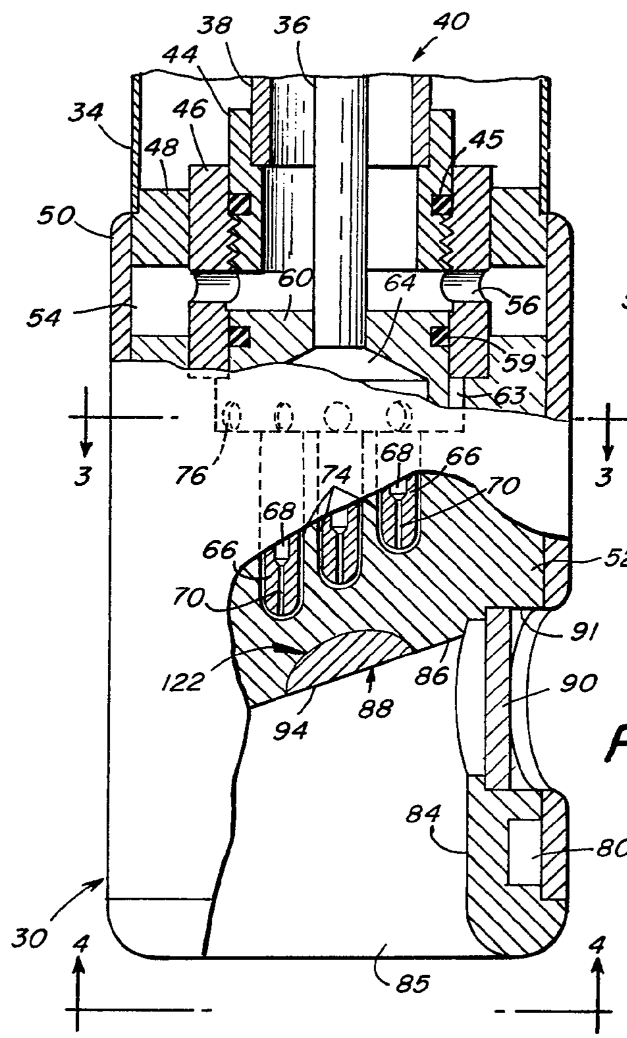

FIG. 2

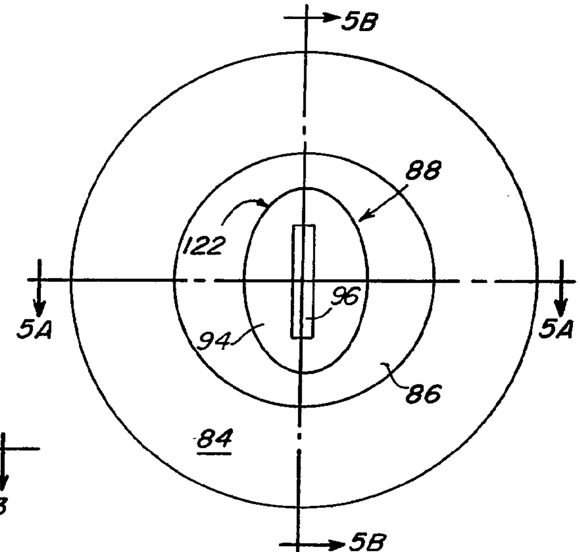

FIG. 4

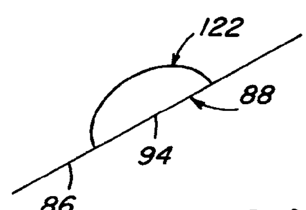

FIG. 5A

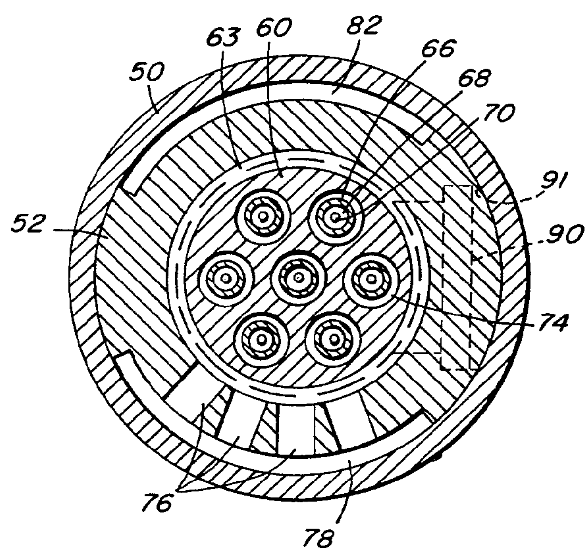

FIG. 3

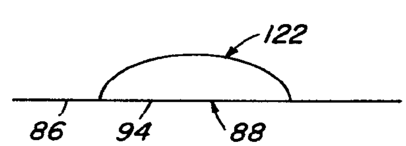

FIG. 5B

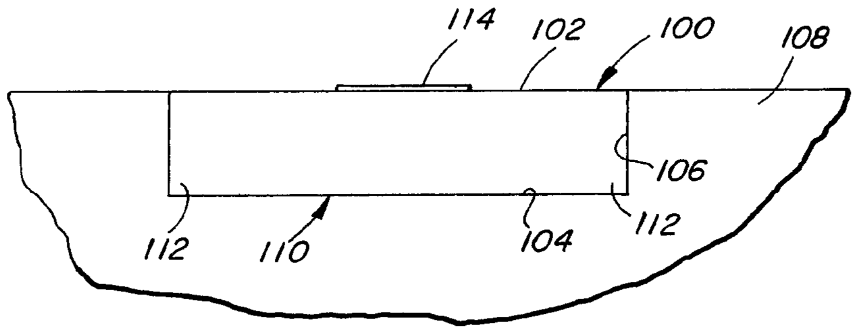

FIG. 6
PRIOR ART

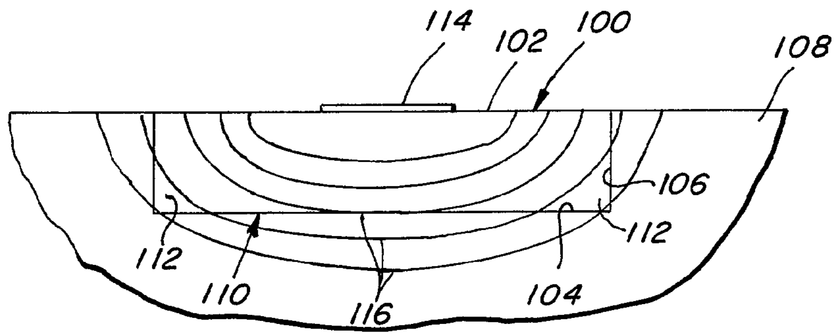

FIG. 7
PRIOR ART

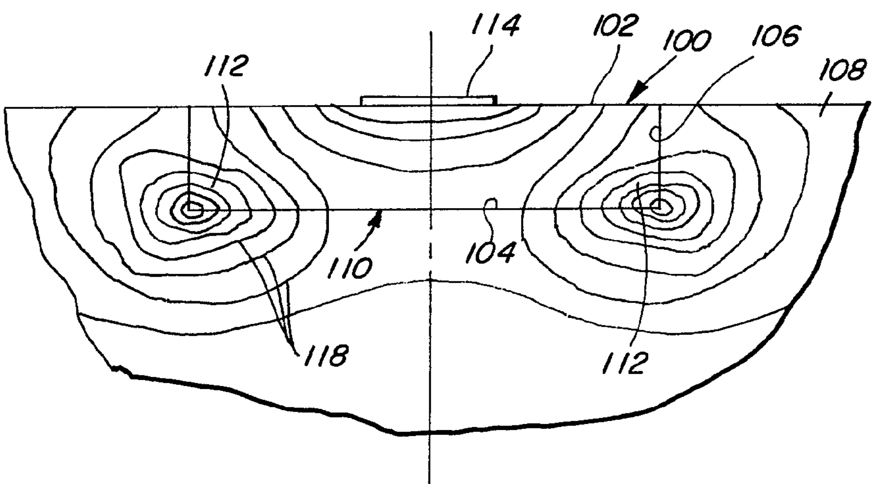

FIG. 8
PRIOR ART

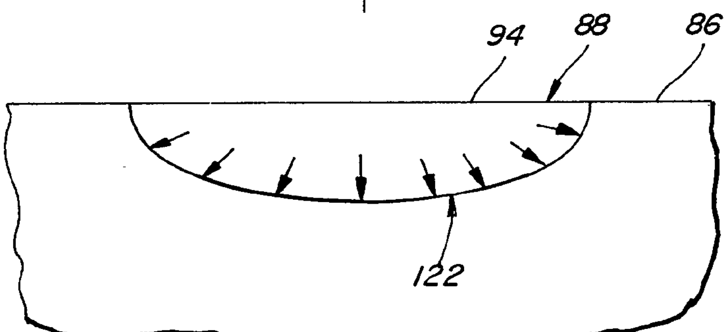

FIG. 9

SPECIFICATION

X-ray targets and tubes

This invention relates generally to a target for an X-ray tube and also an X-ray tube with an improved target.

In an X-ray tube, of the stationary anode type for example, an electron emitting cathode directs a beam of electrons on to an exposed surface of an anode target element made of X-ray emissive material. Since a major portion of the beamed electron energy is converted into heat, the target element is generally attached to an electrically conductive support element which is made of higher heat conductivity material than the X-ray emissive material to function as a heat sink for the target element. Thus, the heat developed in the target element is transmitted to the supporting element which may be in thermal contact with a coolant, such as liquid or air, for example, for conducting the heat away from the tube.

During operation of the tube, it may be found that the target element becomes separated from the support element. Attempts have been made in the prior art to solve this problem, as by bonding the target element to the support element with an interposed layer of mutually compatible material or by increasing the interfacing surface areas of the two materials to achieve a stronger bond, for examples. However, these prior art solutions generally have been unsatisfactory because separation of the target element from support element still occurs, particularly in high power X-ray tubes.

According to the present invention, there is provided an X-ray target comprising a body of X-ray emissive material having a focal surface and comprising a body of X-ray emissive material having a focal surface and having an opposing concave second surface having an edge terminating at the focal surface.

The invention further provides an X-ray target comprising a first body of X-ray emissive material embedded in a surface of a second body of a higher conductivity material, the interface between the two bodies being concave towards the external emission surface of the first body.

The interface can then be shaped to minimize interfacial shear stresses by contouring interface in accordance with an isothermal surface. In operation, there is established in the target body and in the adjacent material of the second body (anode block) a series of isothermal surfaces having configurations symmetrical with a focal spot surface area of the target element. The isothermal surfaces represent respective values of temperature which decrease with increasing distance from the focal spot area.

The target body is provided with a contoured surface in the vicinity of a similarly contoured isothermal boundary to induce in the target body thermal stresses which are within the limits which are X-ray emissive material can withstand. Secured to the contoured surface of the target body is a conformingly contoured surface area of the anode block, so that thermal stresses normal to the interface (compression or tension) are substantially maximized and thermal stressed at an angle to the interface i.e. shear stresses which contribute predominantly to metal fatigue, are substantially minimized. As a result, the target body can withstand relatively high temperature operation without cracking, buckling, or otherwise separating from the anode block.

The anode block also may be provided with cooling means for aiding in shaping the isothermal boundaries established in the target body and the anode block as desired.

For a better understanding of this invention, reference is made in the following more detailed description to the accompanying drawing, wherein:

Figure 1 is an axial view, partly in section, of an X-ray tube embodying this invention;

Figure 2 is an enlarged fragmentary axial view, partly in section, of the fluid-cooled anode shown in Figure 1;

Figure 3 is a cross-sectional view taken along the line 3-3 shown in Figure 2 and looking in the direction of the arrows;

Figure 4 is a plan view taken along the line 4-4 shown in Figure 2 and looking in the direction of the arrows;

Figures 5A and *5B* are respective schematic longitudinal and transverse views taken along the lines 5A-5A and 5B-5B, respectively, shown in Figure 4 and looking in the direction of the arrows;

Figure 6 is a fragmentary longitudinal sectional view of a typical stationary anode target of the prior art.

Figure 7 is a schematic fragmentary view of a respective series of isothermal boundaries established in the prior art stationary anode target shown in Figure 6;

Figure 8 is a schematic fragmentary view of a respective series of iso-stress boundaries established in the prior art stationary anode target as a result of the isothermal boundaries shown in Figure 7; and

Figure 9 is a schematic fragmentary longitudinal view of the anode target of this invention.

Referring to the drawing wherein like characters of reference designate like parts, Figure 1 shows an X-ray tube 10 of the stationary anode type having a tubular envelope 12. The envelope 12 is made of suitable dielectric material, such as lead-free glass, for example, and is provided with respective opposing end portions 14 and 16 of reduced diameter. End portion 14 is integrally sealed to one end of a reentrant portion 18 which extends axially within the end portion 14 and has an opposing end sealed to a conventional stem press 19. The stem press 19 supports within envelope 12 an axially extending cathode structure 20 comprising a helically wound filament 22 made of suitable electron emitting material, such as tungsten, for example. Filament 22 is disposed within a focusing cup 24 made of electrically conductive material, such as nickel, for example, for beaming electrons through an aligned aperture 26 in the closed end of the cup and toward an axially spaced anode structure 30.

End portion 16 of envelope 12 is integrally sealed

to one end of a reentrant portion 32 which extends axially within the end portion 16. The reentrant portion 32 has an opposing end peripherally sealed to an end portion of an axially extending tubular member 34, which is made of suitable metallic material, such as iron-nickel alloy, for example. Axially disposed within the reentrant portion 32 and the tubular member 34 is a coaxial pair of inner and outer conduits 36 and 38, respectively. The inner and outer conduits 36 and 38 are made of metal alloy material, such as steel, for example, and comprise the inlet and outlet fluid conductors, respectively, of a cooling means 40 for removing heat from the anode structure 30. Accordingly, the cooling means 40 is provided with coupling means 42 for connecting the fluid conducting inlet and outlet conduits 36 and 38, respectively, to a source (not shown) of coolant fluid. Coupling means 42 may comprise, for example, a male type fluid connector having a terminal end surface provided with a tapered inlet orifice 37 which communicates, through an axially aligned bore, with the adjacent end portion of inlet conduit 36 in a fluid-tight manner. The male type fluid connector also may have an opposing end portion provided with a radially extending outlet orifice 39 which communicates the adjacent end portion of outer conduit 38 in a fluid-tight manner.

As shown more clearly in Figure 2, the other end portion of inlet conduit 36 extends axially through an annularly spaced bushing 44 made of heat conductive material, such as copper, for example. Bushing 44 has an internally shouldered end portion circumferentially attached to an adjacent end portion of outlet conduit 38, and has an opposing end portion which is externally threaded. The externally threaded end portion of bushing 44 is provided with suitable fluid sealing means, such as O-ring 45, for example, for fluid-tight engagement in an internally threaded end portion of an axially extending support sleeve 46 which is made of heat conductive material, such as copper, for example. The internally threaded end portion of support sleeve 46 has an outer peripheral surface circumferentially attached to an inner peripheral surface of a mounting ring 48 which also is made of heat conductive material, such as copper, for example. Mounting ring 48 has a shouldered end portion circumferentially attached to the other end portion of tubular member 34, and has an outer peripheral surface sealed to an encircling end portion of a hollow cylindrical casing 50 made of heat conductive material, such as copper, for example. The casing 50 extends axially within the larger diameter midportion of envelope 12 (Figure 1) and has a major portion of its inner peripheral surface sealed to an outer cylindrical surface of an encircled anode block 52 which is made of heat conductive material, such as copper, for example.

An end surface of anode block 52 is axially spaced from the adjacent end surface of mounting ring 48 to form therebetween an annular channel 54 having an outer periphery defined by a spanning portion of casing 50 and having an inner periphery defined by a midportion of support sleeve 46. The midportion of support sleeve 46 is provided with a plurality of radially extending ports 56 whereby the annular channel 54 communicates with the adjacent end portion of outlet conduit 38. The adjacent end portion of inlet conduit 36 extends axially through the midportion of support sleeve 46 and is sealed into one end portion of a cylindrical plug 60. Plug 60 has an outer peripheral surface provided with fluid sealing means, such as O-ring 59, for example, for mounting the plug 60 in a fluid-tight manner in the opposing end portion of support sleeve 46. The plug 60 extends out of the opposing end portion of support sleeve 46 and protrudes into an oversized bore in the adjacent end portion of the anode block 52. Consequently, the oversized bore and the protruding end portion of plug 60 form therebetween a cup-shaped channel 63 (Figure 1) which has a closed end formed by the adjacent end portion of support sleeve 46 being sealed to an internally shouldered end portion of anode block 52.

Disposed within the plug 60 is an interior frusto-conical chamber 64 having a smaller diameter end portion disposed in communication with the adjacent end portion of inlet conduit 36. The opposing larger diameter end portion of chamber 64 terminates in an end wall of plug 60 which supports an axially extending array of spaced finger-like projections 66. Each of the projections 66 has disposed in a proximal end portion thereof a respective axial bore 68 which communicates with the chamber 64. The opposing end portions of the axial bores 68 communicate with respective axial jet channels 70 which terminate at the distal end of the respective projections 66. The projections 66 protrude into respective oversized cavities which extend axially further into the anode block 52. The defining wall surfaces of these cavities form with the enclosed projections 66 respective tubular passageways 74 which communicate with the cup-shaped channel 63.

As shown more clearly in Figure 3, the cup-shaped channel 63 communicates through a plurality of ports 76 extending radially through the block 52 to an arcuate channel 78. Channel 78 extends longitudinally between an undercut surface portion of anode block 52 and the adjacent wall portion of casing 50 to communicate with a transversely disposed annular channel 80. The channel 80 is disposed between an annularly undercut surface portion of block 52 and an encircling portion of casing 60 in the end portion of anode structure 30 adjacent the cathode structure 20. Channel 80 communicates with another arcuate channel 82 which extends longitudinally between an undercut surface portion of block 52 and an adjacent wall portion of casing 50 located diametrically opposite the arcuate channel 78. The channel 80 communicates with the annular channel 54 and, hence, with the outlet conduit 38.

Thus, coolant fluid enters the cooling means 40 through inlet orifice 37 of the fluid coupling means 42 to flow through inlet conduit 36 and frusto-conical chamber 64 for distribution to the respective projections 66. As a result, the coolant fluid flows through the respective axial bores 68 and aligned jet channels 70 to be expelled against the opposing surface areas of anode block 52. The coolant fluid then flows through the passageway 74 to cup-shaped channel 63 where it passes through the ports 76 to flow along

the longitudinally extending channel 78 and around annular channel 80. From annular channel 80, the coolant fluid returns along the longitudinally extending channel 82 to annular channel 54 where it passes through ports 56 to flow through outlet conduit 38 to outlet orifice 39.

The end portion of anode block 52 adjacent cathode structure 20 comprises a hollow cylindrical hood 84 defining an axial cavity 85 which extends from the adjacent end surface of block 52 and is aligned with the aperture 26 in focusing cup 24. Cavity 85 has an open end adjacent cathode structure 20 for receiving the electrons beamed from filament 22, and as an opposing closed end formed by a sloped surface 86 of anode block 52. Embedded, as by casting, for example, in the sloped surface 86 and the adjacent heat conductive material of anode block 52 is a target inert or element 88 made of efficient X-ray emissive material, such as tungsten, for example. Target element 88 has an exposed surface 94 substantially flush with the sloped surface 86 of anode block 52, and radially aligned with a window 90 made of X-ray transmissive material, such as beryllium, for example. The window 90 is mounted by conventional means in an aperture 91 which extends through anode hood 84 and is radially aligned with another window 92 comprising an X-ray transmissive portion of envelope 12.

Thus, as shown in Figure 4, the electrons beamed from cathode structure 20 may be focused to impinge on the exposed surface 94 of target element 88 in a desired focal spot area 96, such as a six millimeter by twenty millimeter rectangular area, for example. As a result, the beamed electrons penetrate into the tungsten material of target element 88 and generate X-rays which radiate from the focal spot area 96. However, a major portion of the electrical energy thus expended in the material of target element 88 is converted into heat, which increases the temperature of target element 88 considerably and must be dissipated before damaging the target element. Consequently, the target element 88 is embedded in the higher heat conductivity, copper material of anode block 52. Also, the projections 66 of cooling means 40 are disposed with respect to the target element 88 for promoting uniform cooling thereof and conducting heat out of the envelope 12.

However, as shown in Figure 6, X-ray tubes of the prior art generally utilize a wafer-like target element 100 comprising a right-angle cylinder having respective opposing end surfaces 102 and 104, which are generally flat and substantially perpendicular to an outer cylindrical surface 106 of the element. Target element 100 may be made of efficient X-ray emissive material, such as tungsten, for example, and be embedded, as by casting, for example, in a surface of an anode block 108 made of higher heat conductivity material, such as copper, for example. One of the flat end surfaces, such as 102, for example, may serve as the exposed surface of element 100 while the other flat end surface serves as a bottom surface of the element. Accordingly, the bottom surface 104 and the outer cylindrical surface 106 of element 100 form with the adjacent material of anode block 108 a cup-shaped interface 110. Thus, an abrupt change in thermal characteristics occurs at the interface 110 due to the different thermal expansions for the respective materials of the target element 88 and the anode block 52. Also, interface 110 undergoes an abrupt change in direction adjacent a right-angled annular portion 112 of element 88 where the outer peripheral edge of bottom surface 104 meets the adjacent annular end of cylindrical surface 106.

In operation, electrical energy impinges on the exposed surface 102 of element 100 in a rectangular focal spot area 114 of predetermined size, such as about six millimeters by twenty millimeters, for example. Most of the resulting energy expended in the tungsten material of target element 100 is converted into heat. As a result, heat flows symmetrically away from the focal spot area 114, and across the interface 110 into the copper material of anode block 108. Consequently, as shown in Figure 7, there is established along the direction of heat distribution in element 100 and anode block 108 a series of spaced isothermal boundaries, such as 116, for example. Each of the boundaries 116 has a generally semi-ellipsoidal configuration which is substantially symmetric with respect to the rectangular focal spot area 114. However, a plurality of the isothermal boundaries 116 traverse the cup-shaped interface 110 and extend into the adjacent material of anode block 108, particularly in the vicinity of the right-angle annular edge portion 112 of element 100. Thus, a gradient of temperatures is established along the interface 110 and changes rapidly in the portion of interface 110 defining the right-angle annular edge portion 112 of wafer-like target element 100 where the bottom surface 104 meets the cylindrical surface 106 at right-angles.

As shown in Figure 8, the resulting thermomechanical stresses induced in the different thermal coefficient materials of target element 100 and anode block 108, respectively, establish a corresponding series of spaced iso-stress boundaries, such as 118, for example. Adjacent the focal spot area 114, the iso-stress boundaries 118 have respective ellipsoidal configurations which are substantially symmetric with respect to the focal spot area 114 and conform generally to the contours of the isothermal boundaries 116 shown in Figure 7. However, adjacent the interface 110, the iso-stress boundaries 118 degenerate into respective loops which are spaced closer together and centered around the right-angle annular edge portion 112 of element 100. Thus, there is developed along the right-angle annular edge portion 112, where the interface 110 abruptly changes direction, a torus of high gradient stress forces whose components comprise principal stress forces of shear stress forces. Because of the abrupt change in the interface 110 at the right-angle annular edge portion 112 a corresponding abrupt change may occur in the direction and intensity of the principal stress forces. As a result, the principal stress forces induced shear stress forces which twist the element 100 relative to block 108 and are a major contributing factor in causing metal fatigue. Consequently, these components of thermo-mechanical stress forces exceed the limits of the tungsten and copper mate-

rial, the interface 110 is disrupted, as by twisting of the element 100 relative to anode block 108, for example.

Accordingly, as shown in Figures 2, 4, 5A and 5B, the target element 88 is provided with a semi-ellipsoidal configuration similar to the respective contours of the isothermal boundaries 116 shown in Figure 7. As a result, the target element 88 has a flat exposed surface 94 provided with a shaped periphery, such as elliptical, for example, in the plane of the surface 94 and forms with the adjacent material of anode block 52 a contoured interface 122, such a ellipsoidal, for example. Consequently, as shown in Figure 9, the principal stresses of tension or compression are directed substantially perpendicular to all portions of the interface 122 and are maximal, whereas shear stresses are minimal. The target element 88 may be provided with suitable dimensions for locating the interface 122 adjacent a similarly contoured isothermal boundary of preferred value, such as five hundred degrees Centigrade, for example. Also, the cooling means 40 may be modified to locate the jet channels 70 and encircling passageways 74 with respect to the focal spot area for shaping the isothermal boundaries and associated iso-stress boundaries as desired. Thus, the passageway 74 should be in conformity with the ellipsoidal configuration of isothermal boundaries, for example. As a result, the temperature gradient along the interface 122 may be reduced to a satisfactory value and the resulting thermomechanical stresses may be composed predominantly of principal stresses of tension and compression as well a being directed substantially uniformly perpendicular to all portions of the shaped interface 122.

Although the focal spot area is described herein as being rectangular, it may equally well be provided with other configurations, such as elliptical, for example. Also, although the target element of this invention is shown embodied in a stationary anode type of X-ray tube, it also is applicable to rotary anode types of X-ray tubes where the annular target has a radial cross-section which is semi-elliptical at the interface with the substrate material. Moreover, although the stationary X-ray tube described herein is provided with liquid cooling means, the target element of this invention is easily applicable to stationary anode X-ray tube having other types of cooling means.

Thus, there as been disclosed herein an X-ray tube having a cathode disposed to beam electrons onto a focal spot area of an anode target element made of X-ray emissive material and thermally coupled to a cooling means along an interface which is shaped to conform to the contour of an adjacent isothermal boundary and is substantially symmetrical with respect to the focal spot area.

CLAIMS

1. An X-ray target comprising a body of X-ray emissive material having a focal surface and having an opposing concave second surface having an edge terminating at the focal surface.

2. An X-ray target according to claim 1, wherein the focal surface is substantially flat and the concave surface area is continuously curved in the plane of the focal surface and in at least one plane substantially orthogonal to the focal surface.

3. An X-ray target according to claim 1, wherein the body is substantially semi-ellipsoidal.

4. An X-ray target comprising a first body of X-ray emissive material embedded in a surface of a second body of a higher conductivity material, the interface between the two bodies being concave towards the external emission surface of the first body.

5. An X-ray target according to claim 4, wherein the interface lies substantially on an isothermal surface when the emission surface is bombarded with electrons.

6. An X-ray target according to claim 4, wherein the first body is substantially semi-ellpisoidal.

7. An X-ray target according to claim 4, 5 or 6, comprising cooling means arranged to carry heat away from the second body.

8. An X-ray target according to claim 7, wherein the cooling means are so configured as to tend to maintain an isothermal surface at the interface.

9. An X-ray target according to claim 8, wherein the cooling means comprise coolant channels to the second body, which channels extend to locations so distributed relative to the interface as to tend to maintain an isothermal surface at the interface.

10. An X-ray tube comprising an envelope enclosing a cathode and an anode which comprises a target according to any of claims 4 to 9.

11. A method of mating an X-ray target with a first body of X-ray emissive material embedded in a surface of a second body of a higher conductivity material, wherein the interface is so shaped as to conform to an isothermal surface in the target in operation of the target.

12. A method of mating an X-ray target with a first body of X-ray emissive material embedded in a surface of a second body of a higher conductivity material, to minimize shear stresses between the two bodies in operation of the target.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1982.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.